I claim:

1. A sensor apparatus for tank volume change, comprising a tank, an optical fiber wound on the tank, the optical fiber having opposite ends exposed for receiving and outputting light energy, and a covering over the optical fiber.

2. The apparatus of claim 1, wherein the tank is a cylindrical tank, and wherein the optical fibers are wound in spaced loops in a first helical direction along the cylindrical tank and subsequently are wound in spaced loops in a second helical direction along the cylindrical tank.

3. The apparatus of claim 1, wherein the tank is a tank liner, and the covering comprises a filament winding in a filament wound composite gas storage tank.

4. The apparatus of claim 1, wherein the optical fiber crosses over obstructions and forms bends over the obstructions as the optical fiber is wound on the tank.

5. The apparatus of claim 4, wherein the optical fiber is wound helically in first spaced coils over the tank in a first direction and is wound helically in second spaced coils over the tank and over the first spaced coils in a second direction, and wherein the first spaced coils form the obstructions and the second spaced coils form the bends where the second spaced coils cross over the first spaced coils as pinch points.

6. The apparatus of claim 5, wherein the first and second spaced coils are secured to the tank.

7. The apparatus of claim 5, wherein the bends and the pinch points are secured to the tank with a flexible adhesive.

8. A method of providing sensors for tank volume changes, comprising:

providing a tank;

providing an optical fiber on the tank;

providing obstructions on the tank;

providing pinch points in the optical fiber by crossing the optical fiber over the obstructions;

securing the entire optical fiber or at least the pinch points to the tank;

providing and exposing ends on the optical fiber for receiving light and outputting light; and

covering the optical fiber and the tank.

9. The method of claim 8, wherein the providing the tank comprises providing a cylindrical tank liner, wherein the providing an optical fiber and obstructions on the tank comprises winding the optical fiber in first spaced helical convolutions in a first direction along the cylindrical tank liner and winding the optical fiber in second spaced helical convolutions in a second direction along the cylindrical tank liner and forming the pinch points in the second spaced helical convolutions where they cross over the first helical convolutions of the optical fiber.

10. The method of claim 9, wherein the covering comprises covering the optical fibers with an isolator layer.

11. The method of claim 10, wherein the covering further comprises providing filament windings over the isolator layer of the optical fiber and over the tank liner for supporting internal pressures within the tank liner.

12. The method of claim 9, wherein the securing comprises coating the optical fiber with a settable adhesive as the optical fiber is wound on the tank.

13. The method of claim 9, wherein the securing comprises coating crossover pinch points with a flexible settable adhesive.

14. The method of claim 11, further comprising connecting a light source to one end of the optical fiber and connecting a light sensor to the other end of the light sensor, increasing

pressure within the tank liner, increasing bending in the pinch points by resisting the increasing pressure with the filament windings, and observing transmitted light attenuation in the light sensor related to expansion of the tank liner and increasing bending of the pinch points.

15. Pressure tank apparatus, comprising a tank having an inlet and outlet, an optical fiber secured to an outer surface of the tank and having opposite ends for receiving and outputting light, the opposite ends being fixed near the inlet and outlet for connecting respectively to a light source and to a light sensor as the tank is filled with gas under pressure, the optical fiber crossing on the outer surface of the tank and forming bends and pinch points at the crossings, and an isolator wrap covering the optical filter and filaments encircling the isolator wrap for withstanding internal pressure within the tank liner and resisting expansion of the tank liner.

16. The apparatus of claim 15, further comprising optical couplings connected to the ends of the fibers and secured to the inlet and outlet of the tank liner.

17. The apparatus of claim 15, further comprising thin adhesive connecting the optical filter to the outer surface of the tank line.

18. The apparatus of claim 17, further comprising relatively flexible adhesive at the bends and pinch points.

Table 2-1. Candidate Single Mode Fiber Sensors

	Coating	Core/Cladding /Buffer Diameters [micrometers]	Numerical Aperture	Minimum Dispersion Wavelength [nanometers]	Maximum Attenuation [dB/km]	Bend Diameter (mm)/ dB	Tensile Strength [ksi]
Corning SMF-28	CPC6 Acrylate	8.3/125/245	0.13	1310 1550	0.4 0.3	75/0.05 32/0.50	100
Corning PS-900	NA	NA/80/165	NA	1300	NA	NA	NA
Fiberguide SFS50/125Y BA-0025-1	Acrylate	50/125/250	0.22 (0.12 available)	820	3.8	NA	NA
Fiberguide SFS50/125T DA-0058-6	Polyimide Thermocoat	50/125/145	0.22 (0.12 available)	820	9.0	NA	NA
SpecTran BF04446	Polyimide Pyrocoat	9.3/125/155	0.11	1310 1550	0.7 0.6	17/NA	100
SpecTran BF05446	Acrylate	7.5/125/245	0.17	1550	0.70	NA	NA

Table 4-1. Profile Coordinates & Wall Thickness (inches)

Point	X	Y	Thickness
1	0	0	0.230 - 0.230
2	0.024	0.585	0.230 - 0.218
3	0.049	0.847	0.218 - 0.205
4	0.065	0.979	0.205 - 0.193
5	0.198	1.613	0.193 - 0.180
6	0.496	2.260	0.180 - 0.168
7	0.810	2.639	0.168 - 0.155
8	1.124	2.880	0.155 - 0.143
10	1.752	3.116	0.130 - 0.118
11	2.035	3.140	0.118 - 0.094
12	18.773	3.140	0.094 - 0.118
13	19.056	3.117	0.118 - 0.145
14	19.370	3.034	0.145 - 0.173
15	19.684	2.883	0.173 - 0.200
16	19.998	2.644	0.200 - 0.227
17	20.312	2.272	0.227 - 0.254
18	20.610	1.651	0.254 - 0.282
19	20.759	1.001	0.282 - 0.309
20	21.134	0.695	0.309 - 0.309
21	21.517	0.695	"
22	21.900	0.695	"
23	21.900	0	"

Table 4-2. Tank Wall Properties (see Fig. 4-1 and Table 4-1)

Region	Layer	1	2	3	4
Bottom	Material Thickness Lay Angle	Al 0.188-.230 N.A.	E/E 0.040 78°	E/E 0.040 -78°	N.A.
Middle	Material Thickness Lay Angle	Al 0.094 N.A.	E/E 0.040 12°	E/E 0.040 -12°	E/E 0.160 87°
Top	Material Thickness Lay Angle	Al 0.188-.309 N.A.	E/E 0.040 12°	E/E 0.040 -12°	N.A. N.A. N.A.

Note: Al = 6061-T6 Aluminum; E/E = E-glass/epoxy; Thickness in inches

Table 4-3. Material Orthotropic Properties

Property	6061-T6 Aluminum	E-Glass/Epoxy Uniply
Elastic Modulus (psi):		
EX	10^7	5.6×10^6
EY	"	1.2×10^6
EZ	"	"
Poisson's Ratio:		
NUXY	0.33	.056
NUYZ	"	.26
NUXZ	"	.056
Shear Modulus (psi):		
GXY	3×10^6	6×10^5
Tensile Strength (psi):		
SXT	3.5×10^4	1.5×10^5
SYT	"	4.5×10^3
SZT	"	10^7
Compressive Strength (psi):		
SXC	3.5×10^4	8.8×10^4
SYC	"	1.7×10^4
SZC	"	10^7
Shear Strength (psi):		
SXY	1.8×10^4	8×10^3
SXZ	"	"
SYZ	"	"

Table 5-1. Tank 2 Light Power Test Data

Pressure (psi)	Light Power (μw)					
	1	2	3	4	5	6
0	239.0	238.1	238.4	240.8	242.3	241.8
200	236.8	235.0	235.4	237.2	239.0	238.6
300	235.7	233.1	232.9	234.5	236.2	236.3
400	234.2	230.9	229.9	232.0	233.7	233.9
500	232.3	228.6	226.7	230.1	231.4	230.8
600	230.6	226.3	223.7	227.6	228.5	227.9
700	228.8	224.5	222.1	225.6	226.2	225.2
600	231.5	–	225.0	229.2	229.2	228.1
500	233.8	–	227.5	231.3	231.7	230.0
400	236.0	–	230.2	234.3	234.6	233.3
300	238.6	–	234.4	237.5	237.4	236.1
200	239.9	–	237.7	240.2	239.3	238.0
0	242.3	–	240.2	242.8	242.1	241.5

Table 5-2. Tank 2 Light Power Change

Pressure (psi)	Light Power Change (μw)					
	1	2	3	4	5	6
0	0.0	0.0	0.0	0.0	0.0	0.0
200	-2.2	-3.1	-3.0	-3.6	-3.3	-3.2
300	-3.3	-5.0	-5.5	-6.3	-6.1	-5.5
400	-4.8	-7.2	-8.5	-8.8	-8.6	-7.9
500	-6.7	-9.5	-11.7	-10.7	-10.9	-11.0
600	-8.4	-11.8	-14.7	-13.2	-13.8	-13.9
700	-10.2	-13.6	-16.3	-15.2	-16.1	-16.6
600	-7.5	–	-13.4	-11.6	-13.1	-13.7
500	-5.2	–	-10.9	-9.5	-10.6	-11.8
400	-3.0	–	-8.2	-6.5	-7.7	-8.5
300	-0.4	–	-4.0	-3.3	-4.9	-5.7
200	0.9	–	-0.7	-0.6	-3.0	-3.8
0	3.3	–	1.8	2.0	-0.2	-0.3

Table 5-3. Tank 2 Mean Light Power Change

Pressure (psi)	Mean Change Cycles 1-6 (μw)	Std Dev Cycles 1-6 (μw)	Mean Change Cycles 3-6 (μw)	Std Dev Cycles 3-6 (μw)
0	0.0	0.0	0.0	0.0
200	-3.1	0.4	-3.3	0.2
300	-5.3	1.0	-5.9	0.4
400	-7.6	1.4	-8.5	0.3
500	-10.1	1.6	-11.1	0.4
600	-12.6	2.1	-13.9	0.5
700	-14.7	2.2	-16.1	0.5
600	-11.9	2.3	-13.0	0.8
500	-9.6	2.3	-10.7	0.8
400	-6.8	2.0	-7.7	0.8
300	-3.7	1.8	-4.5	0.9
200	-1.4	1.7	-2.0	1.4
0	1.3	1.4	0.8	1.1